

# **Adaptive optics limits for space telescopes**

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# Adaptive optics limits for space telescopes

## Overview:

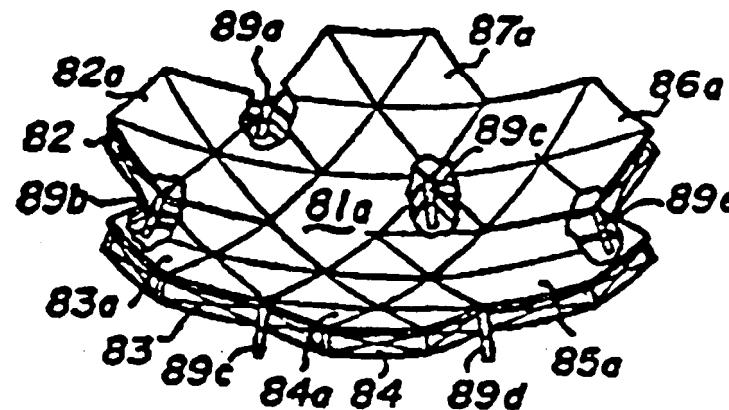
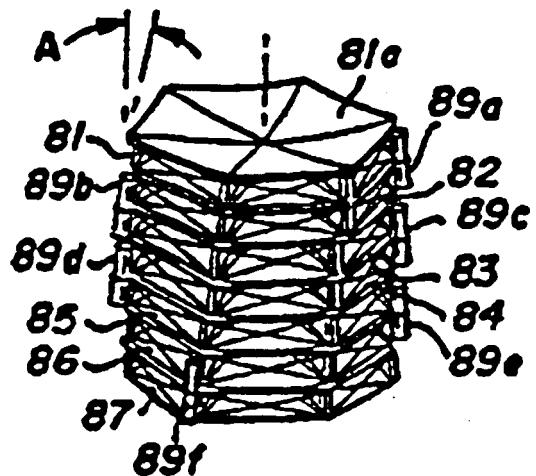
- All future large lightweight optical systems in space will need wavefront compensation  
new technologies enable affordable:
  - ‘large’ apertures ( $> 1m$ )
    - through Lightweight optics and structures
- Control Structure Interaction (CSI) approach to damping disturbances  
to be developed for active and adaptive wavefront corrections  
(‘active’  $\sim < 0.1$  Hz, ‘adaptive’  $\sim > 0.1$  Hz)
- Derive compensation requirements by direct analogy to ground based adaptive optics
  - Kolmogorov power spectrum
  - long and short exposure effects
- IMOS/COMP analysis
  - SRT structure
  - space-time OPD power spectral density functions
    - spatial psd determines stroke
    - temporal fluctuations determine bandwidth

# Adaptive optics limits for space telescopes

Enabling technologies for large lightweight telescopes

## Deployable Solid Surface Reflector Concept

- STOWABLE REFLECTOR
  - TRW PATENT NO. 4,811,034



# Adaptive optics limits for space telescopes

## Need for adaptive optics:

Mission	Aperture	AO need:
Large Aperture UV-visible	3-6-8 -10-16m	Diffraction limited imaging Develop/validate moment actuators for figure control Thermal control to minimize variations
Passively Cooled IR Telescope	3-5-8m	Diffraction limited performance, maintain focus
(Imaging) Interferometer	10-30m	Correct for structural errors Corrections for primary mirror
Discovery class telescope	1-1.5m	Diffraction limited imaging Lightweight mirror figure control Thermal control
Keck 11 and Keck Interferometer	10m	Atmospheric turbulence compensation

# Adaptive optics limits for space telescopes

## Segmented Reflector Telescope (SRT) model:

- Optics

- D=3.75m**

- f/10 Cassegrain**

- 18 hex segment primary**

- Structure

- tetrahedral primary mirror support**

- 3 rod secondary support**

- 15 Hz fundamental

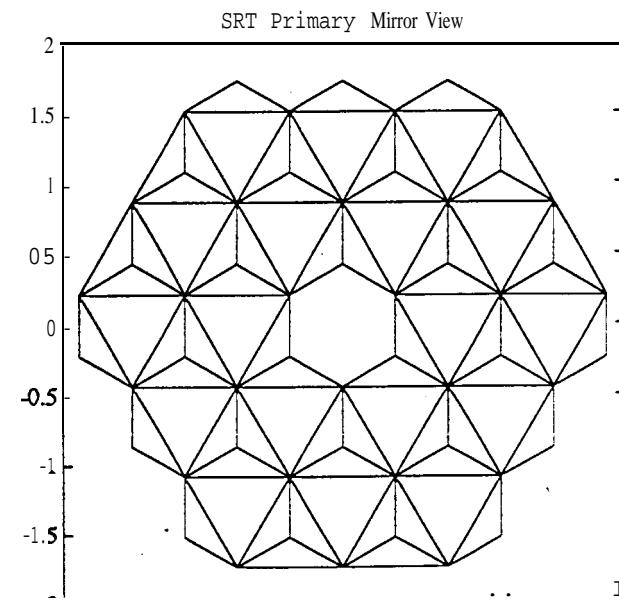
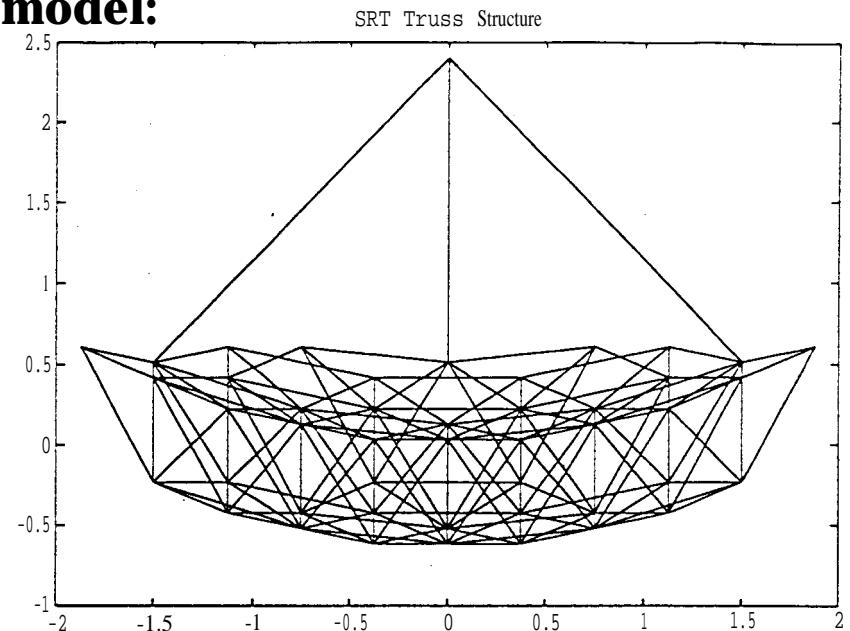
- 291 dof

- 0.1% modal damping

- Disturbance model: HST -type reaction wheels

- 4 harmonics used, [1.0 ,2.0,2.8, 5.2] \*  $\omega$

- $\omega = 50 \text{ rad/s}$



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Space-time optical path power spectral densities:

- space average

$$OPD(u, v, t) = \iint OPD(x, y, t) e^{-i2\pi(ux+vy)} dx dy$$

$$\langle OPD(u, v) \rangle_t = \frac{1}{T} \int_0^T OPD(u, v, t) dt$$

- time average

$$OPD(x, y, f) = \int OPD(x, y, t) e^{-i2\pi ft} dt$$

$$\langle OPD(f) \rangle_A = \frac{1}{A} \int_A OPD(u, v, t) du dv$$

- Power spectral density

$$PSD = |\langle OPD \rangle|^2$$

# Adaptive optics limits for space telescopes

## Zernike falter decomposition:

### ■ References:

Noll, (1976), JOSA, v66, p207-211

Sasiela and Sheldon (1993), JOSA A, v10, p646-650, (Appendix A)

### ■ Zernike mode component and filter function:

$$\mathbf{PSD}(u, v)_j = \mathbf{PSD} \times F(m, n, j, u, v)$$
$$F(m, n, j, u, v) = (n + 1) \left[ \frac{\frac{2J_{n+1}\left(\frac{\sqrt{u^2 + v^2}D}{2}\right)}{\sqrt{u^2 + v^2}D}}{\frac{2}{2}} \right]^2 \begin{cases} 2\cos^2(m\phi) & j \text{ even} \\ 2\sin^2(m\phi) & j \text{ odd} \\ 1 & m=0 \end{cases}$$

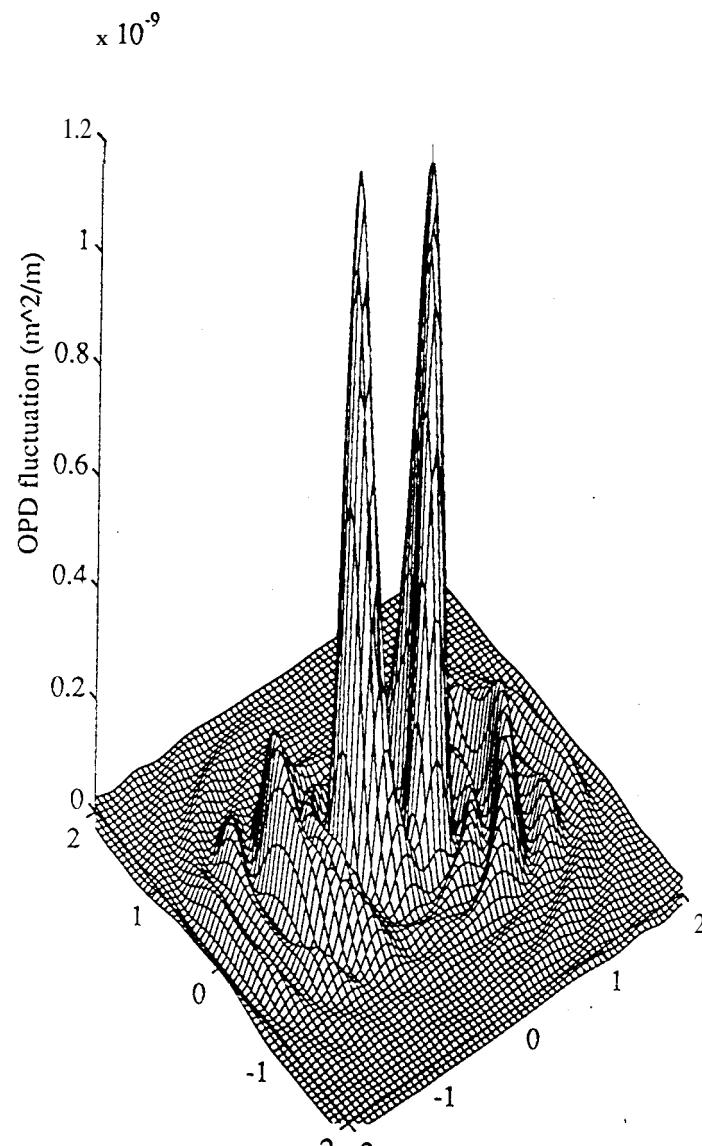
### ■ Variance

$$\sigma^2 = \int PSD$$

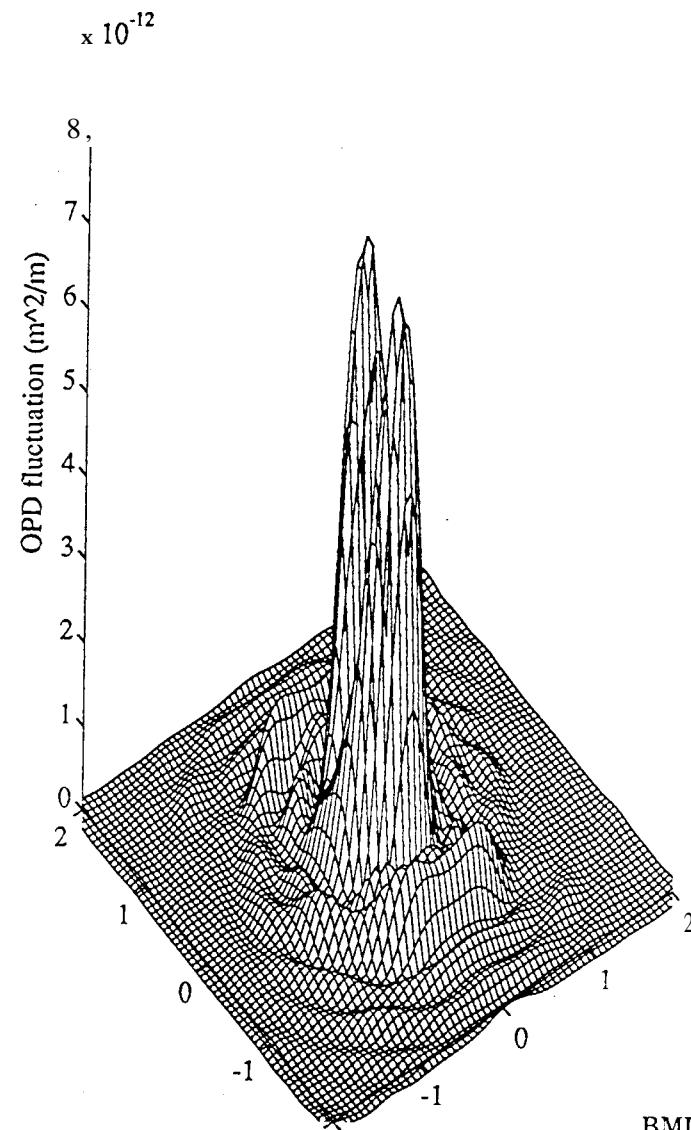
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## Spatial psd with and without passive damping

Piston removed spatial PSD - No Dampers

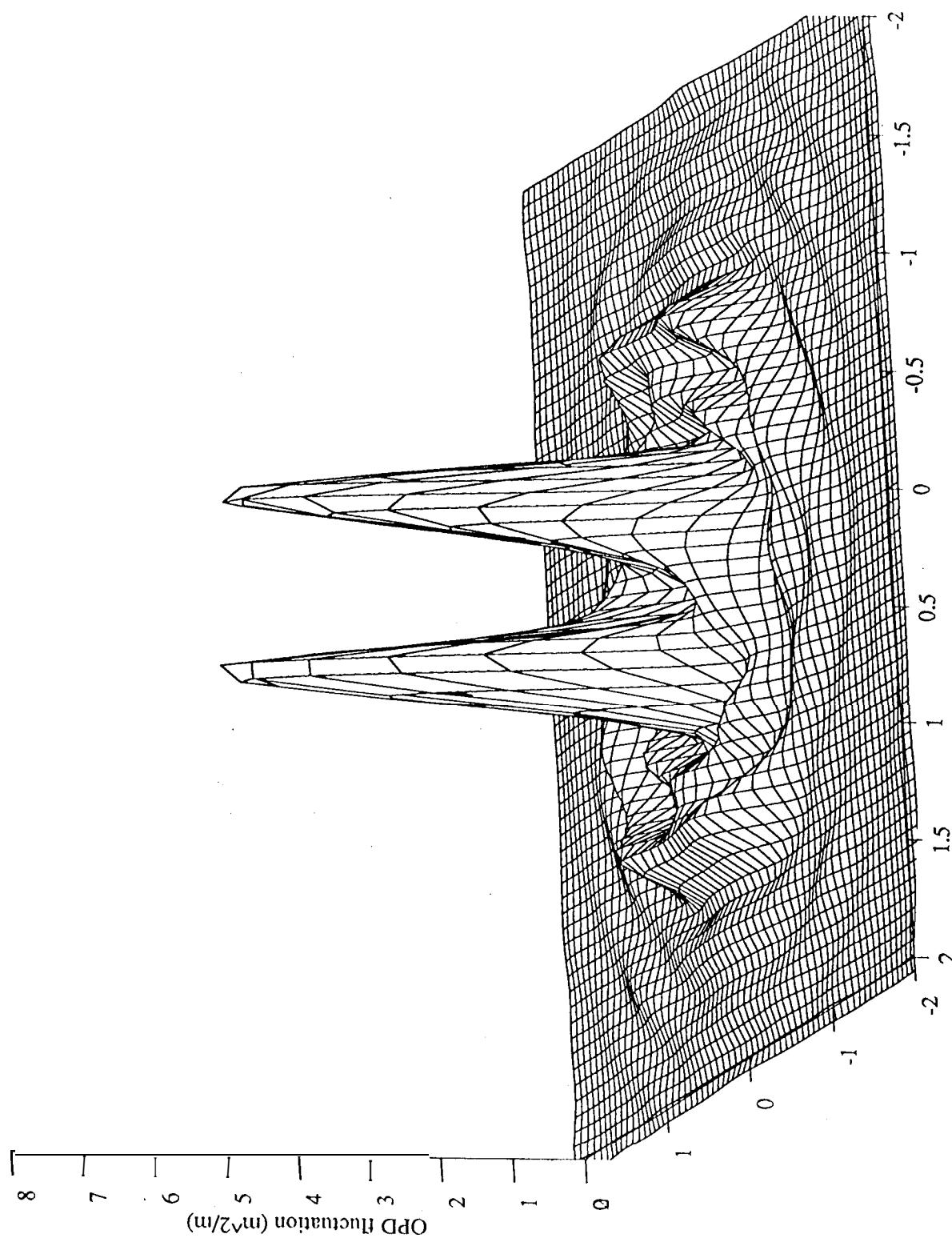


Piston removed spatial PSD - Dampers



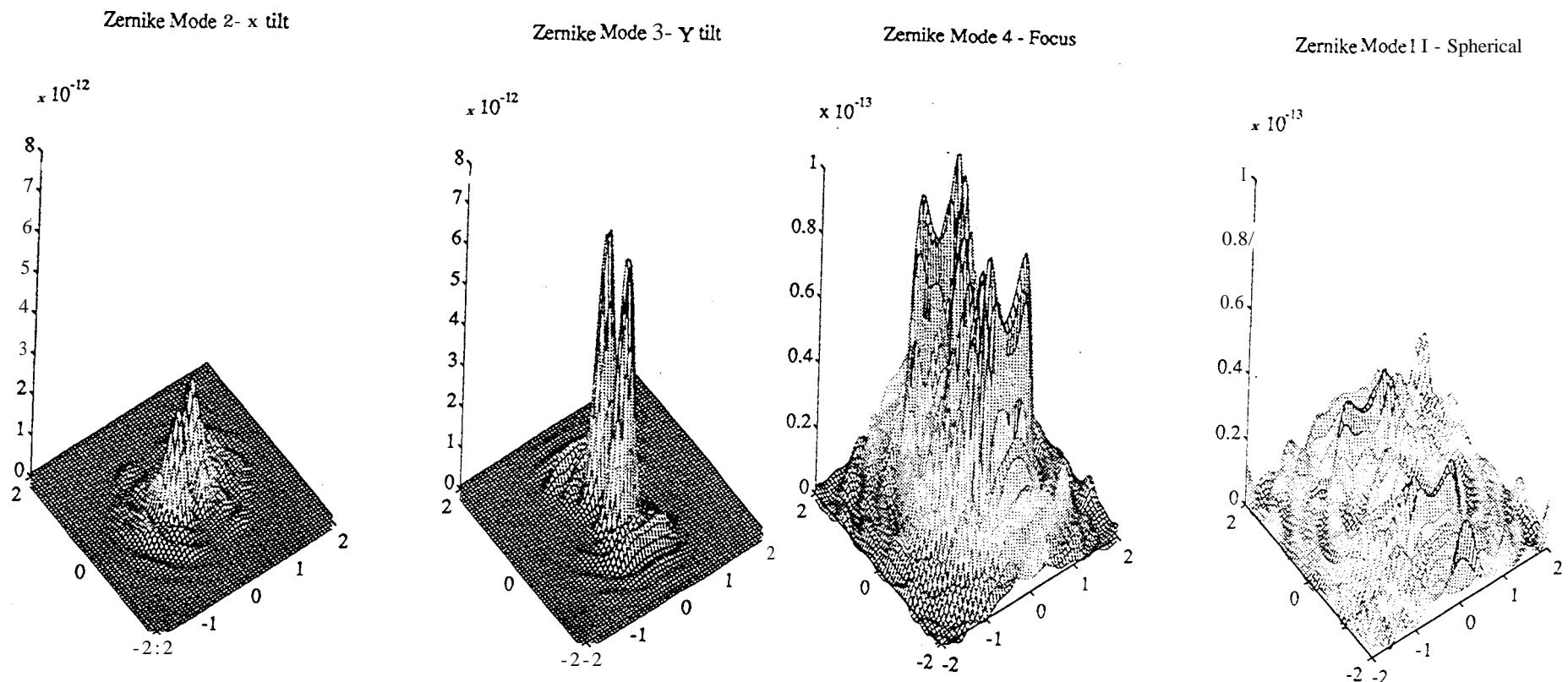
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Piston removed psd:



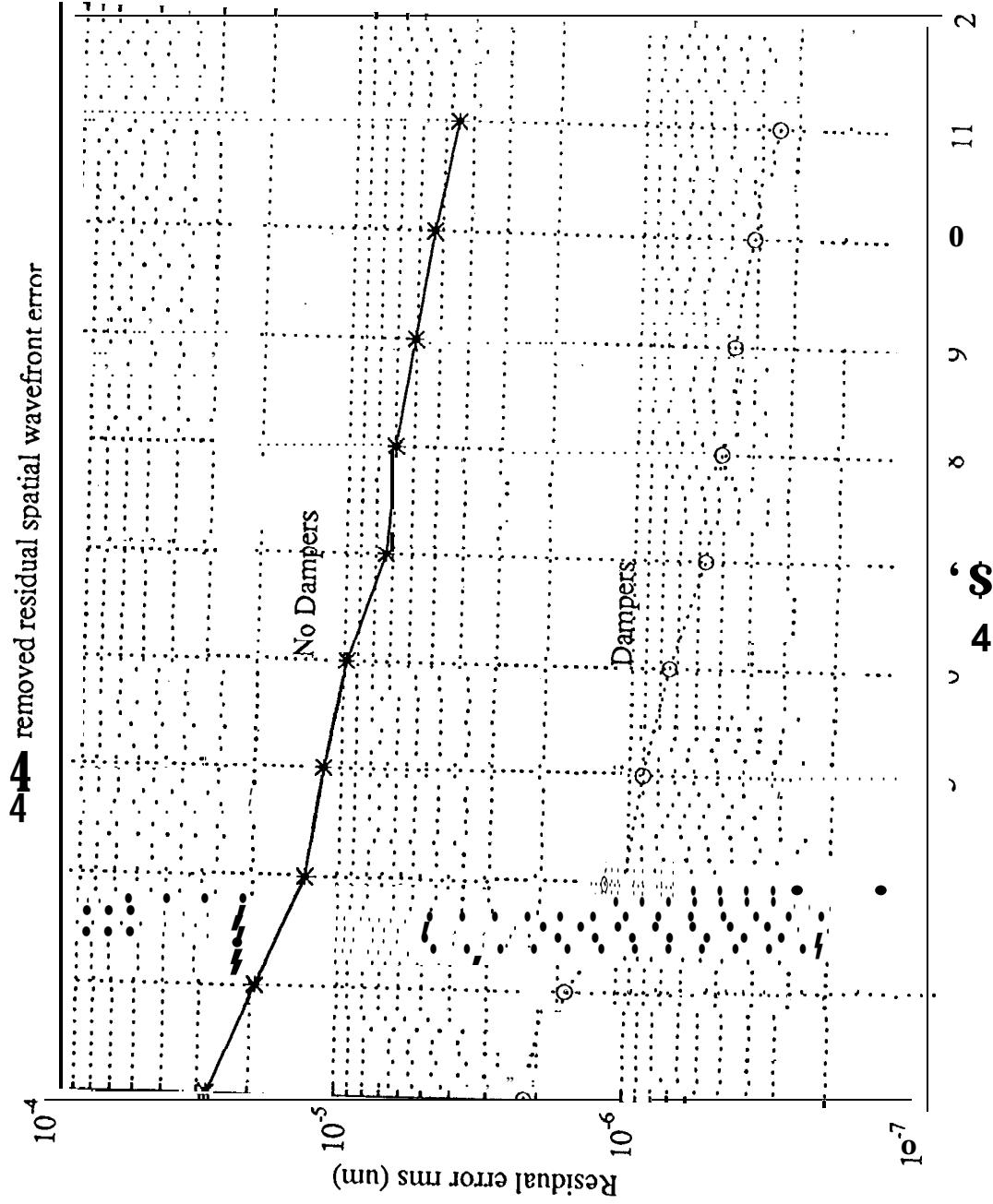
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## Zernike components of spatial psd:



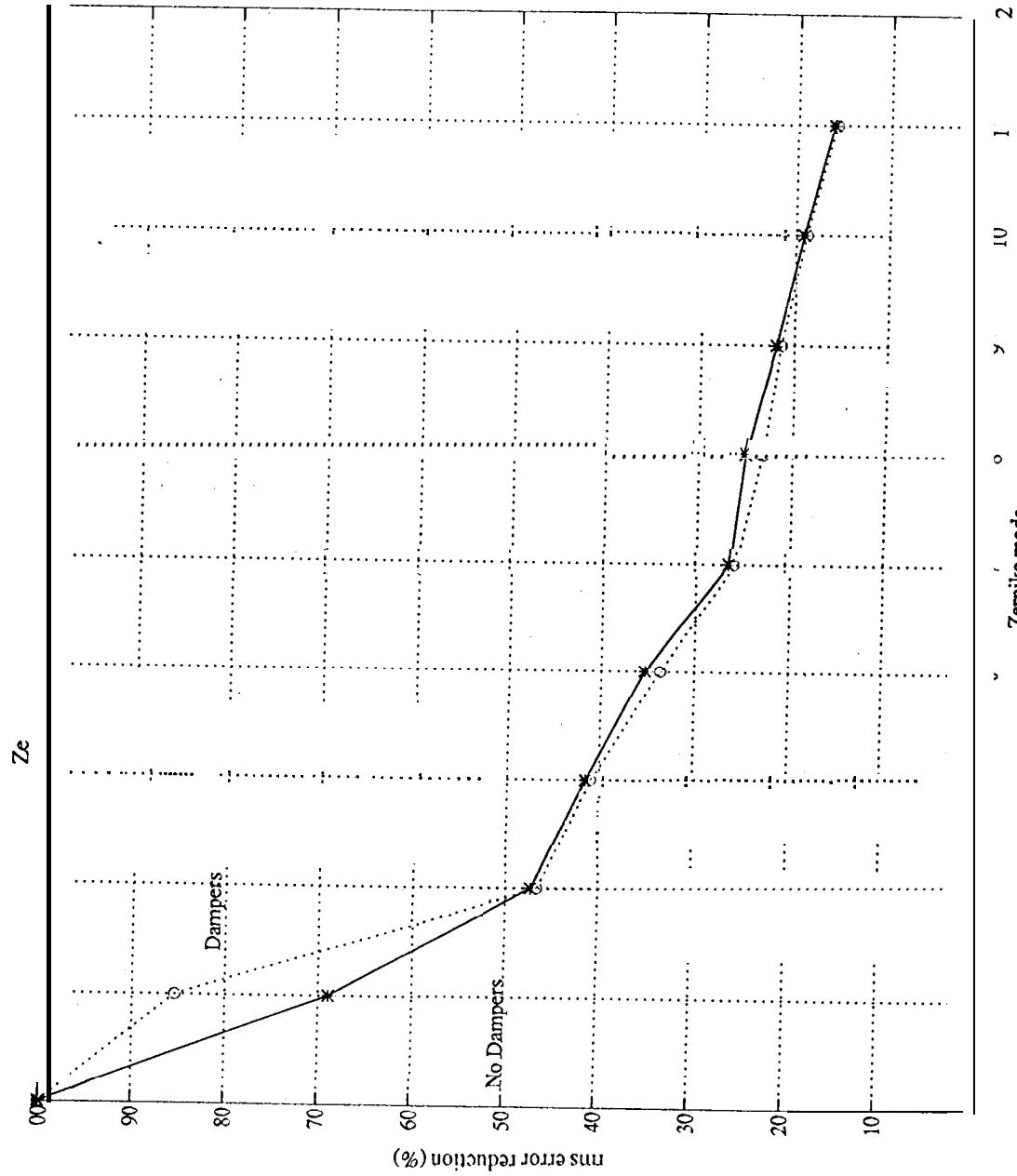
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Residual spatial wavefront error:



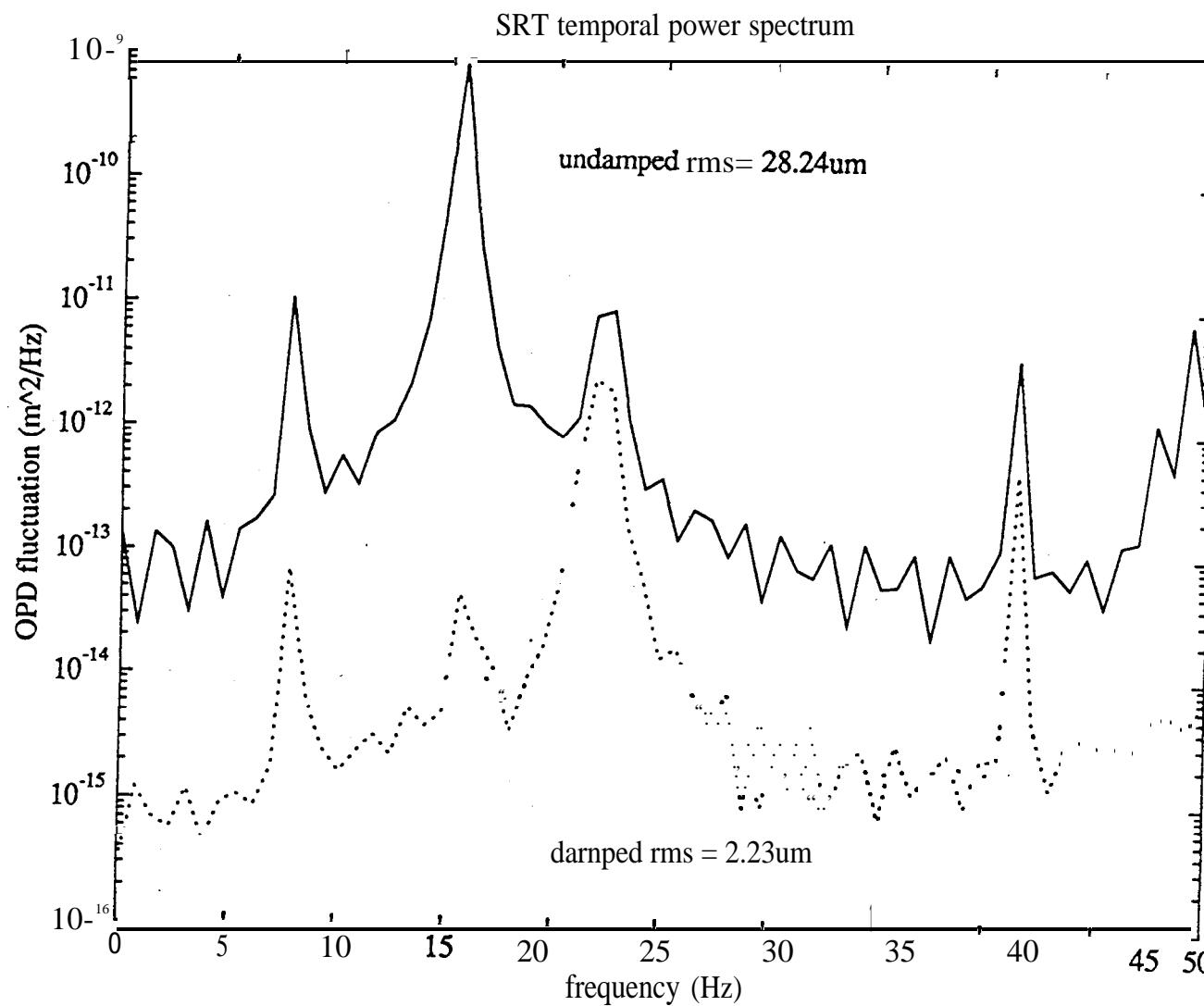
# Adaptive optics limits for space telescopes

Residual spatial wavefront error:



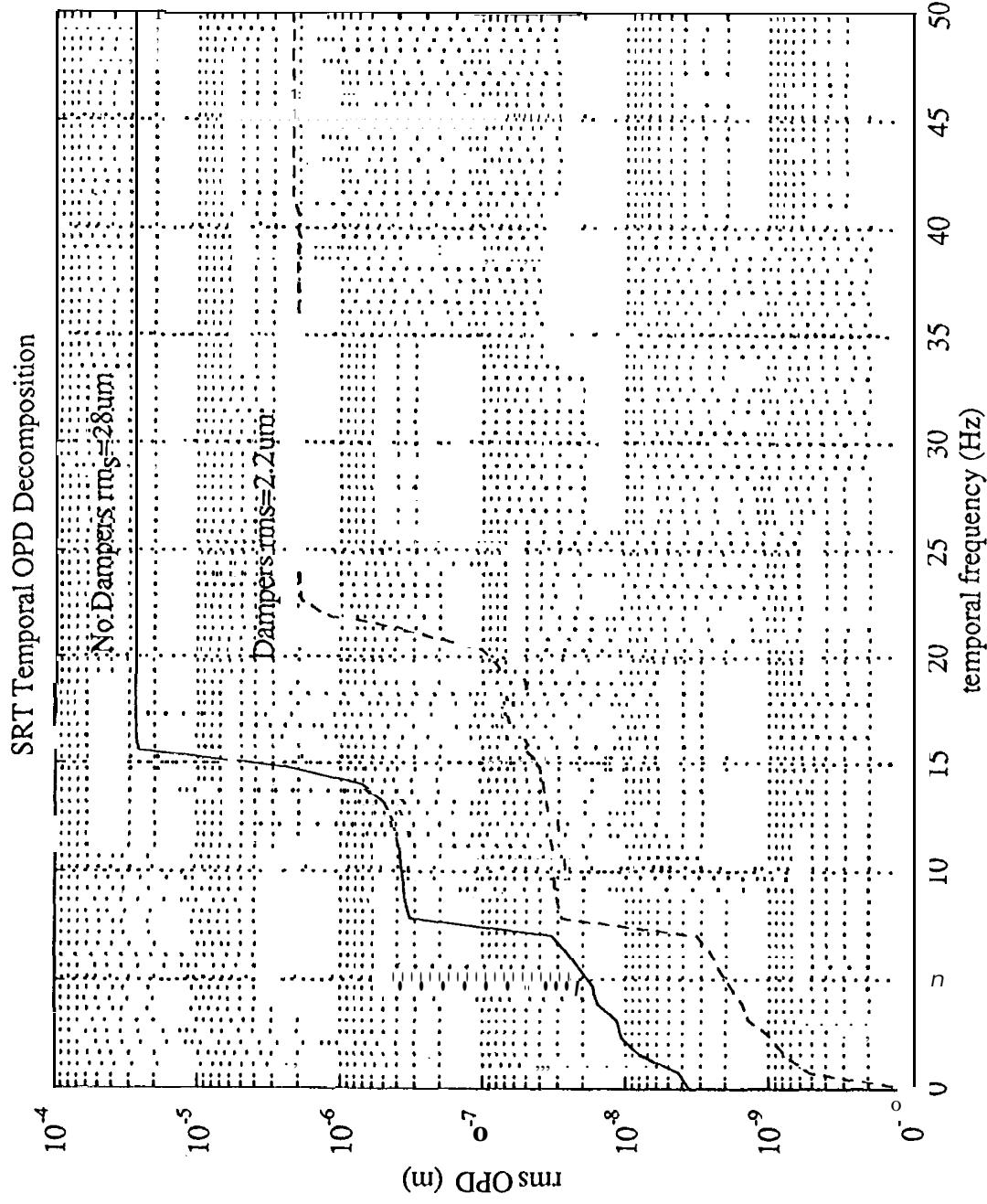
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Temporal psd:



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Temporal rms frequency decomposition:



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## Summary:

- SPT disturbances dominated by tip/tilt corrected through stiffening secondary support structure
- Higher order disturbances will require wavefront compensation
- low order corrections capable of significant performance increase